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Size-distance invariance: Kinetic invariance is different from static invariance

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The static form of the size-distance invariance hypothesis asserts that a given proximal stimulus size (visual angle) determines a unique and constant ratio of perceived object size to perceived object distance. A proposed kinetic invariance hypothesis asserts that a changing proximal stimulus size (an expanding or contracting solid visual angle) produces a constant perceived size and a changing perceived distance such that the instantaneous ratio of perceived size to perceived distance is determined by the instantaneous value of visual angle. The kinetic invariance hypothesis requires a new concept, an operating constraint, to mediate between the proximal expansion or contraction pattern and the perception of rigid object motion in depth. As a consequence of the operating constraint, expansion and contraction patterns are automatically represented in consciousness as rigid objects. In certain static situations, the operation of this constraint produces the anomalous perceived-size-perceived-distance relations called the size-distance paradox.

The size-distance invariance hypothesis (SDIH) asserts that a given proximal stimulus size (visual angle) determines a unique constant ratio of perceived object size to perceived object distance (Epstein, 1977; Epstein, Park, & Casey, 1961; Kilpatrick & Ittelson, 1953). Is it possible to explain the moon illusion and retain this form of the SDIH? To do so, Kaufman and Rock (1962, 1989; Rock & Kaufman, 1962) found it necessary to assume that reports about the perceived distance of the moon were not reports of perception at all. They asserted that verbal statements describing the relative distance of the moon were based on the knowledge that things that look large are near.

But what if reports about the perceived distance of the moon are reasonable descriptions of perceptual experience rather than cognitive deductions? Is it necessary to abandon the SDIH, as a number of authors suggest (Coren, 1989; Day & Parks, 1989; Haber & Levin, 1989), or is it possible to retain an invariant relationship between perceived size and perceived distance? The answer proposed here is that it is possible to retain the relationship only by assuming that static invariance is a special case of a more general kinetic invariance relationship that acts within a rigidity constraint (Hershenson, 1982, 1989b; Johansson, 1964, 1977; Noguchi & Taya, 1981). While the purpose of this paper is to discuss the kinetic invariance relationship, it is necessary first to examine the static formulation.

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STATIC INVARIANCE RELATIONSHIP

Traditional Formulation

The traditional form of the SDIH is derived from the analysis of stationary objects (Epstein, 1977; Gilinsky, 1951; Ittelson, 1951a; Johansson, 1977; Kilpatrick & Ittelson, 1953; Weintraub & Gardner, 1970). This static invariance hypothesis (SIH) describes a relationship between perception and the proximal stimulus. These relationships, simplified for purposes of discussion, are illustrated in Figure 1. The physical (distal-proximal) relationship that produces the proximal stimulus is illustrated in (a), and the psychological (proximal-perceptual) relationship is illustrated in (b). The figure shows a rigid object of size S at a distance D from an observer at P. The object subtends a visual angle ϕ at the eye of the viewer, where visual angle is defined as the envelope enclosing the sheaf of light rays reflected from the object to the viewer at P. Visual angle is used to represent the linear extent of stimulation on the receptor surface because the size of the eye is assumed to be constant. Consequently, the distal-proximal relationship illustrated is $\tan \phi = S/D$, which, for small angles, can be written

$$\phi = S/D. \quad (1)$$

The traditional SIH describes the perceptions that are possible given a constant proximal stimulus. It asserts that perception is constrained by the proximal stimulus (the visual angle ϕ) such that the ratio of perceived size s to perceived distance d is constant (Kilpatrick & Ittelson, 1953):

$$s/d = \phi. \quad (2)$$

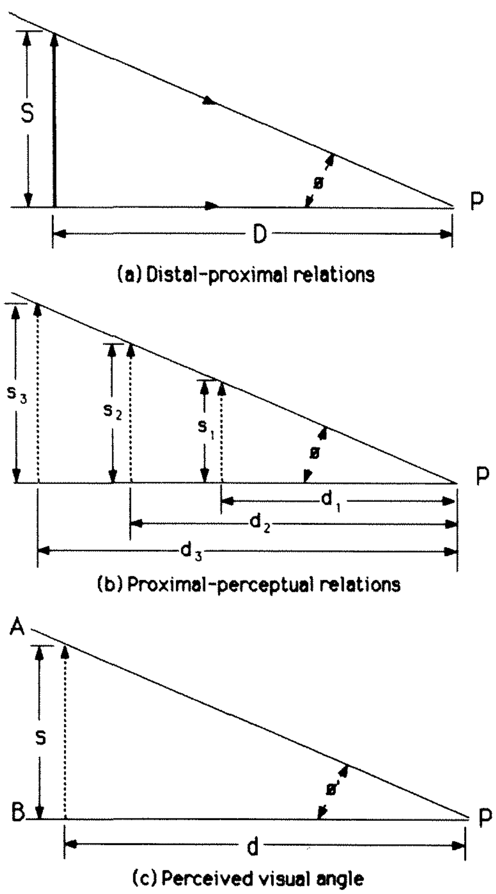

Figure 1. The traditional form of the SIH. (a) The distal–proximal relations for a distal object of size S at a distance D from a viewer at P. (b) The SIH for a given proximal stimulus ϕ. Three possible perceptions are illustrated: an object of size s_1 at d_1, s_2 at d_2, and s_3, at d_3. (c) McCready's (1985) reformulation of the SIH. An object of perceived linear size s appears to be at a distance d. Simultaneously, the edges of the object subtend an apparent visual angle ϕ', the direction difference between PA and PB.

Part b of Figure 1 illustrates three possible perceptions that satisfy the SIH: $s_1/d_1 = s_2/d_2 = s_3/d_3 = \phi$. Note that the SIH does not constrain the absolute values of perceived size or perceived distance—it asserts that their ratio must be equal to the proximal extent. When the SIH is stated in this form, the visual angle is understood as a stimulus input variable, and perceived size and perceived distance are understood as output variables of a perceptual black box. (Of course, the observation and measurement of these output variables involves understanding other black boxes whose output ultimately is behavior, an important distinction that is beyond the scope of the present discussion.)

The static invariance relationship has frequently been used to predict perceived size from perceived distance, and vice versa. However, this apparently simple mathematical transposition of terms masks some important interpretations of the nature of perceptual processing that are not always acknowledged. For example, the task of predicting perceived size from perceived distance appears simple. Typically, the invariance equation is rewritten

$$s = d\phi, \quad (3)$$

a form that is frequently called Emmert's law (Weintraub & Gardner, 1970). What is unusual about this use of the invariance relationship is that perceived distance now plays the role of an input variable. In the traditional view, this term represents input information about distance that affects both the perceived size and the perceived distance of the target object in accordance with the SIH. This input information could take many forms: proximal stimulus input from context such as a texture gradient, cognitive input about the object's relative position in image space, and so forth.

When predicting perceived distance from perceived size, the static invariance relationship is typically written

$$d = s/\phi. \quad (4)$$

Now perceived size plays the role of an input variable. In the traditional view, this term represents input information about size that affects both the perceived size and the perceived distance of the target object in accordance with the SIH. This input information could take many forms: proximal stimulus input from a texture gradient (relative size or size scaling), cognitive input about the absolute size of an object (familiar size), and so forth.

SIH and Constancy

In experiments, static size constancy is usually measured by (defined as) a linear size comparison; that is, a proximal extent of size ϕ_1 appears to be the same linear size as a proximal extent ϕ_2. The two visual-angle inputs may be compared simultaneously or successively. However, the SIH does not describe comparisons—it relates the perceived size and perceived distance of a target object to a specific proximal stimulus of constant size. Consequently, the SIH is typically used in conjunction with additional concepts in explanations of perceptual constancy.

For example, given a proximal stimulus containing two retinal extents, constancy results if the two objects are assumed to be the same size. This can occur if the two proximal extents are produced by similar objects, for example, two ping pong balls or two basketballs. The sequence just described represents an input of size information for two independent applications of the SIH. In this case, the relative perceived distances would be inversely proportional to the visual angles, but that would be a fortuitous consequence of equating the input size values. The link is not a part of the SIH but a result of other factors (e.g., familiar size) that produced the size values. This example invokes familiar size to determine both perceived size and perceived distance according to the SIH, but the constancy is more directly a consequence of the familiarity of the object than the application of this input to the SIH.

The assignment of same-size values could also have been produced by context, scaling, learning, knowledge, or simply an assumption (explicit or implicit) that the objects producing the two visual angles were the same. The point is that these inputs are not features of the SIH but are outside processes that provide information used to determine one of the terms. Constancy is not determined by the SIH but is produced only when additional information is available to determine one of the terms that enter the SIH. Therefore, in the SIH formulation, perceptual constancy is more a consequence of the additional information than of the action of the SIH itself.

Explaining the Size–Distance Paradox

The traditional form of the SIH has been described in three forms. Equation 2 is the clearest because it restates the SIH directly. Equations 3 and 4 mask the fact that, in the the traditional view of the SIH, the input information about distance or about size must result in a perceived size-perceived distance ratio that satisfies Equation 2. What happens to the traditional formulation in explanations of the size-distance paradox? Many proposals have been offered (Hershenson, 1989a), and a small sample is presented here to illustrate how the paradox forces alterations in the traditional formulation (Hershenson, 1989c).

Traditional SIH and the size–distance paradox. Gogel and Mertz (1989) proposed one of the few explanations of the moon illusion that retains the traditional formulation of the SIH. However, it requires the addition of a cognitive processing step between perception and the verbal response. In Gogel and Mertz's explanation, the relative distance of the moon at different elevations is determined by (1) egocentric reference distance (specific distance tendency, oculomotor resting states, etc.), cues that act primarily at higher elevations to make the moon appear closer, and (2) the equidistance tendency that acts at lower elevations to displace the horizon moon toward the more distant horizon. Following the traditional formulation, the combination of these factors makes the horizon moon appear to be both larger and more distant than the zenith moon. The verbal reports that the horizon moon looks closer than the zenith moon are attributed to the perception of the horizon moon as a large off-sized object relative to the perceived (standard) size of the zenith moon (Gogel & DaSilva, 1987a, 1987b; Gogel & Mertz, 1989). The off-sized perception results in the cognitively generated report that the moon on the horizon is closer than the elevated moon.

Partitioning distance information: Registered distance. In their explanation of the moon illusion, Kaufman and Rock (1962, 1989; Rock & Kaufman, 1962) distinguished between perceived distance and *registered distance*, the results of distance cues (input information) on which size perception depends (Wallach, 1990). In effect, they defined d in Equation 3 as input that affects only perceived size. The registered distance of the moon at the horizon is greater than that of the moon in elevation because of the context (pictorial cues, especially horizon, terrain, and clouds). Therefore, the moon appears larger at the horizon than in elevation. Knowledge accounts for verbal reports that the horizon moon looks closer.

Partitioning size information: Perceived visual angle. McCready (1965, 1985, 1986) introduced a new form of the SIH that distinguished two types of perceived size: perceived linear size (s) and perceived visual-angle size (ϕ'), defined as the perceived direction difference between the edges of an object. According to McCready (1985), this is a new concept because traditional definitions of perceived visual angle treat linear and angular size responses as two ways of measuring the same perceptual experience. It is also a different type of concept because perceived size and perceived distance are affected by cues, whereas perceived visual angle is not. McCready assumed that the experiences associated with linear size (s) and angular size (ϕ') are not only qualitatively different; they are simultaneously existing perceptual experiences.

These concepts are illustrated in Figure 1c for the same physical situation illustrated in Figure 1a. The object has a perceived linear size s at perceived distance d. Simultaneously, it subtends a perceived visual angle ϕ', defined as the difference between the perceived directions PA and PB. In McCready's formulation, the two types of perceived size are not interchangeable in the SIH. They are related according to a new SIH:

$$s/d = \phi'. \quad (5)$$

Given this relationship, the size-distance paradox vanishes, because it is defined as misperceived visual angle.

Thus, for McCready, the perceived-size-perceived-distance ratio is an invariant function of the perceived visual angle (ϕ'), not the visual angle normally used to describe the proximal stimulus (ϕ). In this sense, it has a unique status in the processing sequence. The two visual angles are related because

$$\phi' = m(R/n) = m\phi, \quad (6)$$

where R is the retinal extent of stimulation, n is the distance from the retina to the nodal point of the eye, and m is the phenomenal magnification, the ratio of perceived to actual visual angle.

Additional variables. Another way the traditional form of the SIH has been retained is in an enlarged theoretical context. For example, the explanations of the moon illusion proposed by Wagner, Baird, and Fuld (1989) and Gilinsky (1951, 1980, 1989) maintain the basic relationship of the traditional SIH but add new terms. Wagner et al.'s (1989) analysis of the distal variables that determine the proximal representation of objects includes the orientation of the object with respect to the ground. They proposed that veridical perception results when the visual system calculates the inverse of this transformation, a form of the traditional SIH that includes an applied orientation as an additional term. The inverse transformation provides the basis for their explanation of the size-distance paradox. Gilinsky's (1951, 1980, 1989) formulation also introduces new concepts into the relationship. Her analysis takes into account the normal viewing distance for an object, the distance at which the object appears to be its true size for a given observer, and the absolute upper limit of perceived distance. These parameters vary with observers, with perceptual development, and with conditions of observaton.

The purpose of this brief description of proposed explanations of the size-distance paradox was to illustrate the different types of alterations in the traditional SIH that its solution requires. The remainder of this article describes a fundamentally different approach based on an analysis of kinetic invariance.

KINETIC INVARIANCE

In the static invariance relationship, visual angle is constant and perceived size and perceived distance can vary. In the kinetic invariance relationship, an expanding proximal pattern is perceived as an approaching rigid object, and a contracting pattern is perceived as a receding rigid object (Hershenson, 1982, 1989b; Johansson, 1977).[1] Thus, in kinetic invariance, solid visual angle changes, perceived size remains constant, and perceived distance varies. These relationships are sometimes summarized by saying that an expansion or contraction pattern is the proximal stimulus correlate for the perception of motion in depth (Gibson, 1950, 1966). But this correlation will not suffice as a description or as an explanation because the perceived size of the object is not included. The object that appears to be moving in depth does not appear to shrink or enlarge as it moves. This constancy of perceived size in kinetic situations has been emphasized by Johansson (1950, 1958, 1964, 1974a, 1974b, 1977), who explicitly argued that the projective invariants in the proximal stimulus are the fundamental determiners of object constancy (size and shape constancy) in kinetic situations.

A change in proximal size may occur in one meridian, or in two or more meridians.[2] It is important to distinguish between these cases because they have different consequences in perception. Proximal size change in a single meridian (described by a changing visual angle) does not produce stable perceptions. It may appear to be a line or rectangle whose size is changing in the frontal plane, or a rigid object rotating in depth around a point or line, or translating in depth (Börjesson & von Hofsten, 1972; Hershenson, 1991; Johansson & Jansson, 1968; Swanston & Gogel, 1986). Proximal size change in two or more meridians (described by a changing solid visual angle) yields stable perceptions: An expanding pattern is perceived as an approaching rigid object and a contracting pattern is perceived as a receding rigid object (Börjesson & von Hofsten, 1972, 1973; Hershenson, 1982, 1989b, 1991; Ikeda, 1960; Ittelson, 1951b; Johansson, 1950, 1958, 1964, 1974a, 1974b; Noguchi & Taya, 1981).[3] Wallach and O'Connell (1953) first demonstrated the importance of stimulation over two or more meridians in their landmark study of the kinetic depth effect. Although many of their experients demonstrate the point, it is most clearly seen with the rotating "T" stimulus whose crossbar appeared to change in size in the frontal plane. When the "T" was altered so that the crossbar was no longer at right angles to the vertical member, its shadow appeared to be produced by a rotating rod of constant size.

Thus, the normal viewing situation involves kinetic stimulation that suggests the following kinetic invariance hypothesis (KIH): An expanding or contracting solid visual angle produces a constant perceived size and a changing perceived distance. The distal-proximal and proximal-perceptual relationships for the KIH are illustrated in Figure 2. For clarity, the figure shows one meridian of change. Figure 2a shows the distal-proximal relationship for an expansion pattern: a rigid object of size S moves from D_1 to D_2 (ΔD), directly toward a viewer at P, producing a proximal expansion pattern indexed by the visual-angle change ($\Delta\phi = \phi_1 - \phi_2$). For small angles, the relationship may be written:

$$\Delta\phi = S/\Delta D. \qquad (7)$$

The proximal-perceptual relationships are illustrated in Figure 2b. If s is the perceived size of the object and d is its perceived distance, a given visual-angle change ($\Delta\phi$) is perceived as a rigid object (s = K) moving in depth ($\Delta d = d_1 - d_2$). The KIH relates the perceptual experience to the proximal stimulus:

$$s/\Delta d = \Delta\phi. \qquad (8)$$

Instantaneous time samples (at t_i) obtained from Equation 8 describe the relationship between a specific value

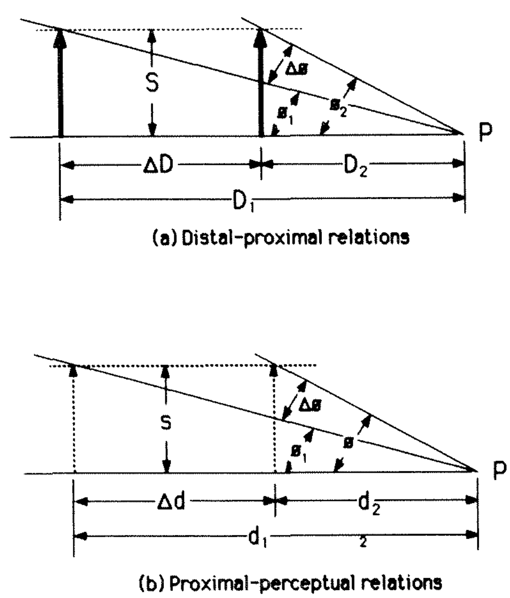

Figure 2. The KIH. (a) The distal-proximal relations for a distal object of size S moving toward a viewer at P, from D_1 to D_2, producing the increasing retinal size indexed by the visual angle change $\Delta\phi = \phi_1 - \phi_2$. (b) The proximal-perceptual relations for the KIH. A rigid object of size s appears to move toward the viewer at P over a distance $\Delta d = d_2 - d_1$.

of perceived size (s_i) and a specific value of perceived distance (d_i) such that $s_i/d_i = \phi_i$. That is, instantaneous values of the KIH satisfy Equation 2, the SIH.

It should be clear that the KIH presents a problem different in kind from that of the SIH: neither motion in depth nor rigidity is contained in the proximal stimulus.[4] What is needed for the KIH to operate is a mechanism that mediates between the changing solid visual angle and its representation in consciousness as a rigid object moving in depth. The need for such a mechanism is underscored by the fact that the representation of this activity in consciousness must be qualitatively different from the proximal pattern. One such mechanism is an *operating constraint*—activity of a system that automatically produces a specific response to specific patterns of stimulation.

Applying this idea to kinetic situations suggests that, when stimulated by proximal expansion or contraction patterns, the perceptual system automatically produces the perception of rigid objects moving in 3D (Hershenson, 1982, 1989b). Hereafter, this activity is called the *rigidity constraint*. The concept of a rigidity constraint is different from concepts associated with static invariance, because it refers to automatic activity that is a consequence of the structure of the perceptual system. It is a property of the perceptual system, not additional input from stimulation such as that from texture or surrounding terrain, or from another system, such as input information from memory about the familiar size of an object.

Formally, the constraint may be understood as a scaling of perceptual space to maintain a constant perceived size (rigidity). The relationship can be described by a scaling factor (β_i) that transforms the changing solid visual-angle input (ϕ_i) into a constant perceived size:

$$s = K = \beta_i \phi_i. \qquad (9)$$

Thus, the scaling factor varies inversely with the input (visual angle) to maintain the perception of a rigid object. A major consequence of this scaling is that, in conjunction with the KIH, the rigidity constraint produces perceived motion in depth (Hershenson, 1989b, 1991). Therefore, the scaling factor varies directly with perceived distance. Thus, perceived rigidity and perceived motion in depth are linked by the scaling function and the KIH.[5]

The Rigidity Constraint and Perceptual Constancy

The kinetic analysis reveals at least two components to perceptual constancy: perceived linear size and perceived rigidity. Perceived *linear size* is the quantitative experience that an object has a specific metric size, whereas perceived *rigidity* is the qualitative experience that an object has not changed in size (has not enlarged or shrunk) over time. Thus, it should be clear from the respective analyses that the manner in which constancy is treated represents another major difference between the static and kinetic formulations of the invariance relationship. In the static version, constancy usually refers to the perceived linear size of an object because we say constancy has occurred when perceived linear size is veridical. In contrast, the kinetic formulation refers to the perceived rigidity of an object.

The difference between perceived rigidity and perceived linear size is illustrated in Figure 3 for the KIH. The figure shows that the same change in retinal extent can produce two different perceptions with regard to the linear size of the object but still satisfy the KIH with respect to perceived rigidity. The proximal stimulus is represented by a visual-angle change ($\Delta\phi = \phi_1 - \phi_2$). Under the KIH, a given proximal change will be perceived as a rigid object moving in depth. Two possible perceived rigid objects are pictured, one of linear size s_1 and one of linear size s_2. According to the KIH, the proximal stimulus $\Delta\phi$ could appear to be the rigid object of linear size s_1 moving toward the viewer from d_1 to d_2. But the identical proximal stimulus could appear to be the rigid object of linear size s_2 moving from d_3 to d_4. In both cases, the object appears to be rigid, to move toward the viewer, and to satisfy Equation 8, the KIH. However, neither the SIH nor the KIH determines perceived linear size—it is determined only when additional information is available to the perceiver. Thus, an object may be perceived as rigid or even as the same linear size at two different distances,

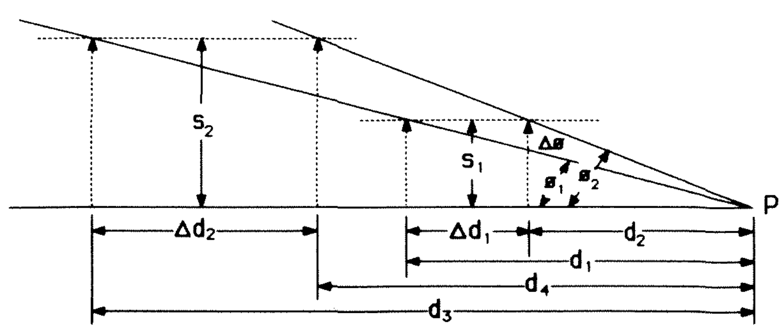

Figure 3. Two of the many possible perceptions given an expanding proximal stimulus $\Delta\phi$. A rigid object of perceived linear size s_1 could appear to move toward the viewer at P over a distance $\Delta d_1 = d_1 - d_2$. A second possible perception is the rigid object of size s_2 that moves toward the viewer at P over a distance $\Delta d_2 = d_3 - d_4$.

but the perception may not be veridical—the perceived size and the distal size may still differ.

Static Stimulation Under Kinetic Invariance: The Size–Distance Paradox

Kinetic invariance and the rigidity constraint describe how moving stimuli come to be represented in consciousness as rigid objects moving in depth. How are static stimuli represented under this kinetic model of perceptual activity? The answer is that, in most cases, perceived size and perceived distance are more or less veridical, and the SIH is satisfied. There is a vast literature that can be taken as support for the SIH in this form. But this literature does not provide evidence for a rigidity constraint, nor does it support the contention that static invariance is a special case of kinetic invariance. Static situations that demonstrate the operation of the rigidity constraint are anomalies—situations in which static invariance appears *not* to hold. These situations are often described as examples of a size–distance paradox and have been taken as evidence that the SDIH is not a law of perception (Kilpatrick & Ittelson, 1953).

Situations that give rise to the size-distance paradox share common attributes. First, they are static; that is, the paradox occurs when the visual angle subtended by the target object is not changing. Second, inputs from other sources induce change in either the apparent size or the apparent distance of the target object. These inputs could be relative depth information from the surround (as in the moon illusion), previous stimulation by an expansion or contraction pattern (as in the spiral aftereffect), changing oculomotor information (as in micropsia), or changing relative size (as in Day & Parks's, 1989, experiment, see below). In these situations, the normal automatic activity described as the rigidity constraint produces the size-distance paradox—an increased perceived size when perceived distance decreases and a decreased perceived size when perceived distance increases.

The paradoxical outcomes can be understood as effects of the rigidity constraint, the scaling mechanism that produces constancy. Recall that the scale factor varies inversely with the position of the target in perceptual space (not necessarily physical space). In normal circumstances, this factor results in perceived rigidity or constant size when the input (visual angle) is changing. But in paradoxical situations, visual angle is constant and the scaling factor applied is constant. Therefore, when the target object's position in perceptual space is altered, the scaling factor is incorrect for its new position—it is too large when the object appears close and too small when the object appears more distant. Because the system operates automatically for all inputs (static and kinetic alike), the incorrect scaling factor is applied to produce an increased perceived size when the target appears near and a decreased perceived size when the target appears farther away.

The paradox is illustrated in Figure 4. Figure 4a shows normal (kinetic) processing but with a static input: A distal object of size S at a distance D from a viewer at P subtends a visual angle ϕ. (Once again, although the simplified figure shows stimulation along a single meridian, it should be understood that the stimulus subtends a solid visual angle at the eye.) Whenever the stimulus covers more than a single meridian, the rigidity constraint is activated and the KIH applies despite the fact that the input is constant (ϕ = k). The rigidity constraint is manifested in the scaling weights: β for the object at D, β_h when the object appears to be at D_h, and β_z when the object appears to be at d_z. The figure shows that perceptual space is scaled for rigidity even when the target object is static, an assertion that there is a single operative perceptual system for static and kinetic stimuli.

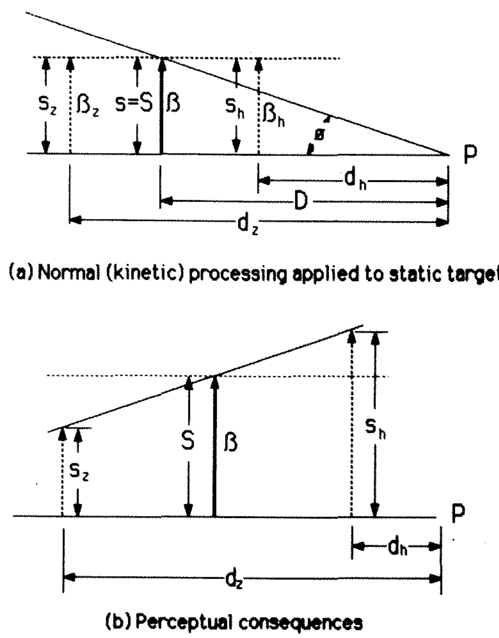

Figure 4. Operation of the KIH in paradoxical situations. (a) The constant visual angle ϕ is produced by an object of size S at distance D. The object may appear closer, at d_h, or more distant, at d_z. The active rigidity constraint is illustrated by the weights $\beta = \beta_h = \beta_z$ when the object is perceived as rigid at D, d_h, or d_z, respectively. (b) The perceptual consequences. The weight applied at d_h ($\beta_h = \beta$) is too large, and therefore $s_h > s$. Similarly, the weight applied at d_z ($\beta_z = \beta$) is too small, and therefore $s_z < s$.

Figure 4b shows the perceptual consequences. The constraint requires scaling weights to produce rigidity regardless of the additional information: $d_h < D < d_z$. (In the illustration, $s = S =$ K for simplicity, but it is important to remember that rigidity is not veridicality.) Because visual angle is constant, the scaling weight applied is constant (β). But β is larger than β_h, the weight required at d_h to maintain constancy. Therefore, β applied at d_h results in an enlarged perceived size. Similarly, β is smaller than β_z, the weight required to maintain rigidity when the object appears to be at d_z. Therefore, β applied at d_z results in a diminished perceived size. The consequence is $s_h > s_z$. Thus, when visual angle is constant and additional input alters perceived size or perceived distance, the consequence of the rigidity constraint is an inverse relationship:

$$sd = K. \tag{10}$$

This outcome of the constancy scaling mechanism is surprising at first. But it should not be. We feel quite comfortable with the idea that a changing proximal stimulus is represented in consciousness as a rigid object, an object of unchanging size. What is unusual, then, when the same mechanism produces a changing size in perception in response to an unchanging proximal input?

Specific examples: It should be apparent from the subscripts that the situation described in Figure 4 is Hershenson's (1982) explanation of the moon illusion. In that case, additional contextual input is provided by the horizon, terrain, and perhaps the sky. An additional process, the equidistance tendency, determines the relative perceived distance of the moon as a function of elevation within this context. The result is that perceived distance varies directly with elevation—the horizon moon appears closer than the zenith moon: $d_h < d_z$. But the resulting perceived sizes are not equal—the closer-appearing moon (s_h) looks larger than the more distant-appearing moon (s_z) because of the scaling operation of the rigidity constraint.

These relationships can be readily observed in a variation of the spiral aftereffect. Normally, looking at a stationary spiral after watching the spiral rotate produces the spiral aftereffect. With casual viewing of this sequence, a depth component is visible, but it is difficult to describe the size changes that are observed. Clearly, while the rotating spiral is needed to induce the depth changes in the test stimulus, the spiral is not necessarily the appropriate test figure. The spiral itself is a test figure of no clear size dimension, and it is embedded in the plane of the disk on which it is printed. Therefore, it is difficult for a spiral to appear to move in depth independently of the disk. The perceptual changes are more noticeable when a test object such as a white disk suspended by black threads is used. When illuminated in an otherwise dark room, the disk appears to be floating in darkness. When viewed after fixating a contracting rotating spiral, the disk clearly appears to move in depth toward the viewer. What is more important, however, is that the disk also appears to increase in size—the exact change in perception predicted from the rigidity constraint and the KIH (Hershenson, 1982).

Another example may cement the point. Day and Parks (1989) described an experiment in which a stimulus subtending a constant visual angle appeared to change in perceived size and distance. This was accomplished by having subjects form an afterimage of a disk on a grid illuminated in such a way that only the lines were visible. In a dark room, subjects reported that the afterimage appeared smaller as they approached the grid and larger as they backed away. These changes are not surprising and appear to support the SIH: relative size determined by the grid is such that, when the viewer is near the grid, perceived size is smaller than when the viewer is farther away from the grid.

However, there are important differences between the afterimages in this experiment and those in typical afterimage experiments. Normally, afterimages are "projected" onto a surface, and they occlude a portion of the surface. The size of the occluded portion can be measured as linear size or as visual angle. Emmert's law works for afterimages because it affirms a trigonometric truism—the relationship between the two measurements. The context in which afterimages were produced in the Day and Parks experiment was different from this typical situation. Because their afterimages were not projected onto a surface and did not occlude a visible portion of the field, afterimage size was determined by relative size with respect to the grid. However, their perceived depth in darkness was determined by the scaling mechanism. Walking toward or away from the grid produced a continuous size change: $s_n < s_f$, for near and far extremes. With visual angle constant, the rigidity constraint produced the perceived distance relationship described by Equation 10: $d_n > d_f$. The afterimage appeared smaller and farther away when the subject was near the grid, and appeared larger and closer when the subject was far from the grid.

CONCLUSION

This analysis of kinetic invariance leads to two important general conclusions: First, the simple SIH holds if it is understood as a relationship that describes an instantaneous time sample of the more general KIH. Second, if the first conclusion is correct, then perceived size and perceived distance are *not* independent perceptual qualities.

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NOTES

1. Because the discussion concerns size-distance invariance, it should be clear that the reference for the expansion or contraction patterns is an object in space. Of course, expansion and contraction patterns are also produced by head and body movements, and also refer to the context for the objects (Gibson, 1950).

2. It is frequently noted that visual angle can change in size in one dimension or in two, but there is an important difference between the terms *meridian* and *dimension*. A simple illustration will clarify the difference. Two dots (points) moving toward or away from each other are moving in one dimension (colinear) and in a single meridian. Two parallel lines moving toward or away from each other are moving in two dimensions, but the size change involves only a single meridian. Three or more points moving toward or away from a single point are moving in two dimensions and produce size change in more than one meridian.

3. See Ittelson (1951b), Johansson (1977), and Hershenson (1982) for historical reviews. Marmolin (1973) reported an apparent discrepancy between simultaneous measurements of perceived size and perceived distance that is sometimes cited as evidence against the KIH. Johansson (1977) attributed this finding to oculomotor distance registering or the specific distance tendency. Alternatively, the measurments may have contained errors (see Hershenson, 1982, footnote 2, for a discussion of this point).

4. Of course, Gibsonians would argue that the proximal stimulus contains a "correlate" that specifies rigidity. Todd's (1982) analysis in terms of trajectories is probably the most elaborate attempt to uncover such a correlate.

5. A similar idea has been proposed by Shepard and his co-workers (Shepard, 1981, 1984; Shepard & Cooper, 1982) to relate distal motions to the motions of mental images.

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